N69-78387

18. APPLICATION OF RADIATION DATA TO SYNOPTIC ANALYSIS AND TO STUDIES OF THE GENERAL CIRCULATION

By JAY S. WINSTON, *Chief, Planetary Meteorology Section, Meteorological Satellite Laboratory, U.S. Department of Commerce, Weather Bureau*

Some of the maps of radiation data presented in previous papers illustrate applications of these data for synoptic usage. For the most part data obtained in the 8- to 12-micron window region, channel 2 of the TIROS radiometers, will be used synoptically. As data become available from the other channels, the broad infrared and the reflected solar radiation measurements will be more useful for studying the overall heat budget of the earth and its atmosphere and the general circulation.

The synoptic usage is considered first. Figure 18–1 is an example, given in reference 1, of radiation data for the 8- to 12-micron window region obtained in a pass of TIROS II across the Atlantic Ocean. These data are expressed in terms of effective radiating temperature in ° C. The isopleth interval is in terms of radiative intensity; thus, the isotherms are labeled −10°, −17°, −25°, and so forth. There is not an equal thermal difference from one isotherm to another. The wide variations in temperature are of interest in figure 18–1 (the letter *C* indicates cold and the letter *W* indicates warm). Note the very cold values in the northern section of the occlusion in the middle Atlantic where there was a rather intense low and a well-developed upper low center. The warmer values farther south along the front are still a little cooler than some adjacent regions. The warmest area is found to the west of the front. A very cold area is found at the western edge of the data, the forerunner of another wave cyclone developing to the west. The temperature pattern of the frontal system approaching Europe is not nearly so well defined as those of the other frontal systems in the central and western Atlantic. Actually, a warm axis is found near this frontal zone, with lower temperatures extending northward just east of the front and also some cold areas north of the warm front. In general, the relationship is not a very classic one, if it is assumed that cold values signify moderately high clouds and warm values signify clear to scattered clouds or low broken to overcast clouds. The data can thus show differences in frontal structure and, combined with cloud pictures, could be very useful. Unfortunately, no cloud observations are available for comparison with this radiation chart.

Most of the preliminary studies to evaluate these data in detail should be over areas where there are rather good conventional synoptic data. An example of such a study of an orbital pass over the United States is presented in figure 18–2. These data obtained on November 23, 1960, at about 1810 GMT are again for the 8- to 12-micron window region. The temperatures are expressed in terms of ° K. The isotherm interval is 10° K; the dot-dash lines are intermediate 5° K isotherms. These same data in analyzed printout form were presented in paper 16. The present analysis was prepared from the unsmoothed data before the machine printout data were available, so there are differences between this analysis and the machine version which result from differences in smoothing and locating the data points. An important feature of interest is along the frontal zone near the east coast of the United States where very low values of radiation were obtained (fig. 18–2). This front was nearly stationary with wave developments along it. The lowest radiation temperature values tend to be mainly southeast of the front. Note the sharp gradient of temperature to the north and west of the front. Generally, there are high temperatures from

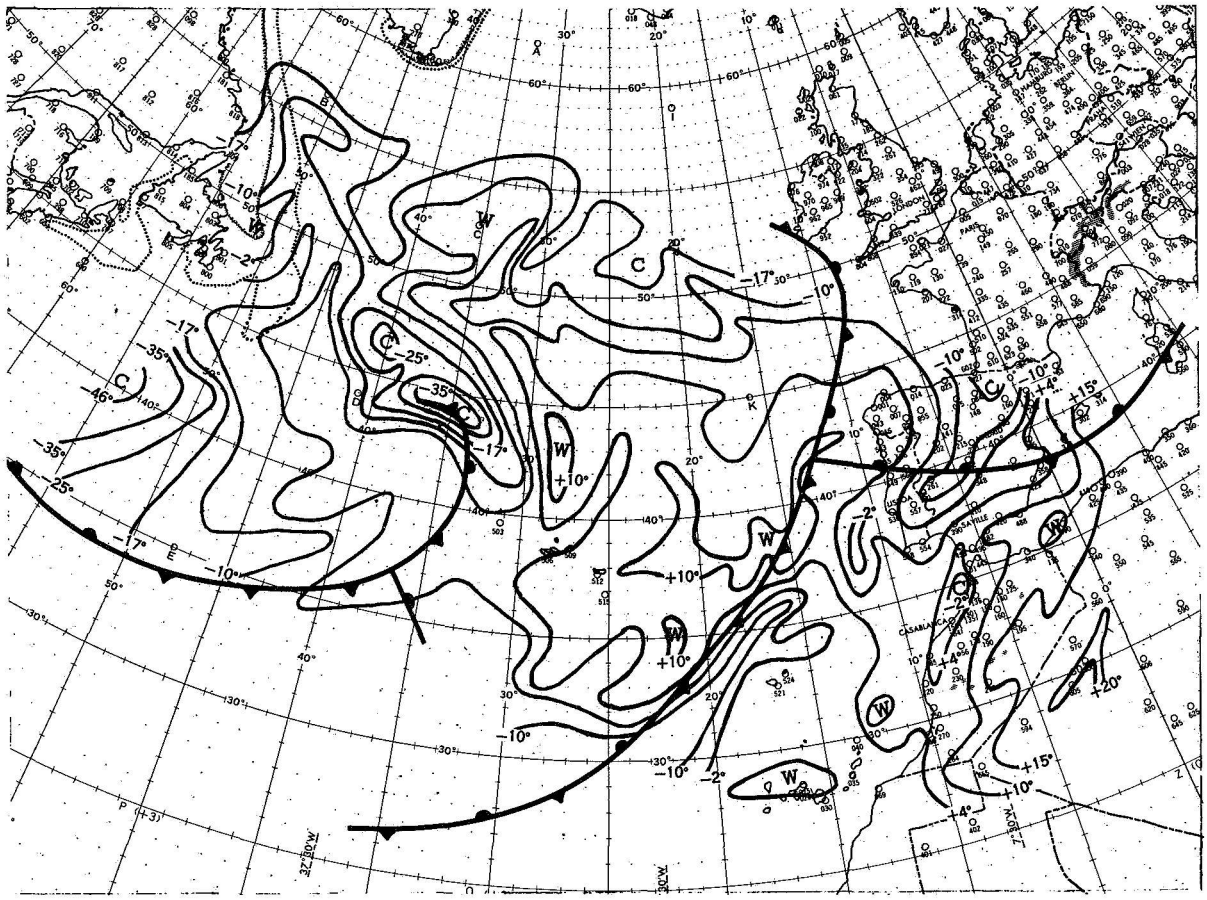

FIGURE 18–1. Radiation data 8- to 12-micron region obtained by TIROS II. Temperature in ° C.

the Appalachian Mountains to the central part of the United States. The temperature gradients throughout this region are relatively small. Farther west over the Great Plains and Rocky Mountains more complicated patterns are found.

Figure 18–3 is a cloud chart based on conventional data only. (TIROS II pictures were available for this time but were rather poor.) This chart was based not only on surface data but also on radiosondes, pilot reports, and vertically pointing cloud radar at one station (Washington, D.C.). It shows not only areas of overcast, broken and scattered clouds, and clear skies but also an analysis of the heights of cloud tops in the broken and overcast areas. Only three contour lines have been drawn: 30,000, 10,000, and 5,000 feet. It is interesting that the very lowest radiation values were in the area where the tops of the upper cloud layer of an extensive multilayered cloud system were more than 30,000 feet. Pilots reported heights of 33,000 feet or more in this area. Furthermore, the area of rainfall nearly coincided with the zone of the highest cloud tops and lowest radiation temperatures (i.e., less than about 250° K).

Note the very abrupt change in cloud height over the region near 39° north and 75° to 80° west from the high cirrostratus above 30,000 feet to a layer of altostratus-altocumulus with tops at about 15,000 feet and then to broken and scattered stratocumulus clouds at about a hundred miles to the northwest. The radiation gradient (fig. 18–2) was extremely strong in this region, showing a very sharp change from low to high values over Pennsylvania, where the clouds become scattered stratocumulus and then the skies clear toward the northwest. In the Midwest (Mississippi and Ohio River Valleys, Great Lakes, and eastern Great Plains) satellite-measured temperatures were within

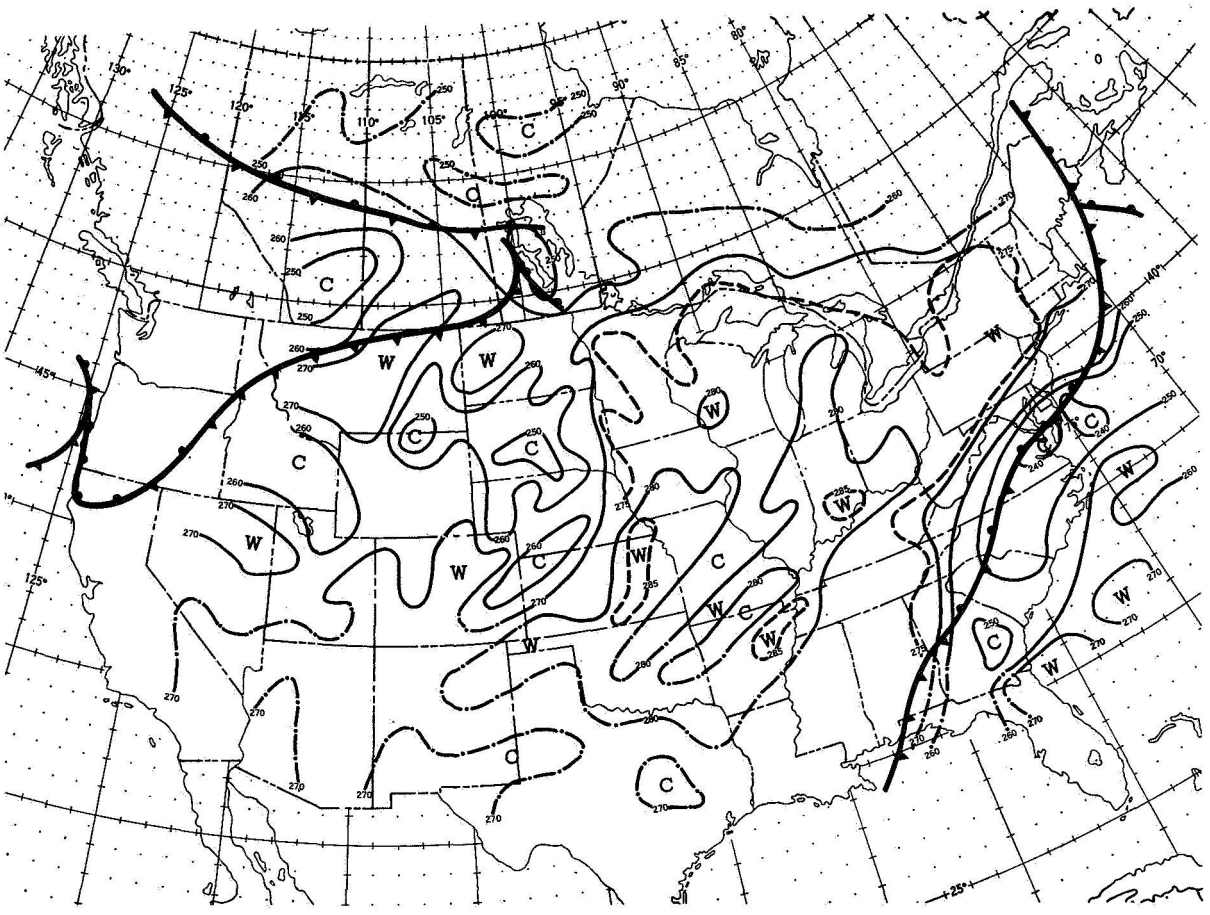

FIGURE 18–2. TIROS II radiation data 8- to 12-micron region, 1810 GMT November 23, 1960. Temperatures in ° K.

about 1° to 5° K of the surface air temperatures for this time of day, near local noon on November 23, 1960. An interesting area over the Great Plains (the Dakotas, Nebraska, and Wyoming) was covered by cirrus and cirrostratus clouds which apparently were rather thin. Underneath this cirrus and cirrostratus was an altostratus cloud layer with tops estimated to be about 18,000 feet. This is the area where two cold centers are shown in figure 18–2. These roughly coincide with the shape of the altostratus cloud area underneath the cirrostratus (fig. 18–3).

Figure 18–4 shows estimates of the heights of the tops of clouds derived in part from the satellite temperature values of figure 18–2 and with the aid of the vertical temperature distribution. The temperature distribution of the standard atmosphere could possibly be used, but on the average a better estimate can be made over most of the Northern Hemisphere by use of isotherm charts prepared daily in the National Meteorological Center for several constant pressure surfaces. In many areas these may be crude estimates, but in other areas they are rather good. Over the United States for this date (November 23) analyzed isotherm patterns were used at several constant pressure surfaces to obtain crude "soundings" at many points within this pattern of satellite temperatures. Entering each sounding with a satellite temperature value from figure 18–2, a height value was obtained for each point. These are the heights shown in figure 18–4. Note that over the high cloud area in the eastern United States heights of 27,500 feet or more were obtained. Between this region and Pennsylvania there is a sharp drop in heights to 5,000 feet or less, which generally agrees with figure 18–3. Southwestward along the frontal zone the heights continue relatively high, but then there is a very sharp decrease to 5,000 to 10,000

feet over the south (Georgia and Alabama). This region is still overcast, as may be seen in figure 18–3, but the overcast consists of stratocumulus clouds with tops around 5,000 to 10,000 feet which agree well with the estimates made from the radiation data. In the area of scattered clouds or clear skies, these height values shown in figure 18–4 essentially do not have much meaning. They generally give rather low values, which are close to the surface of the earth. Over the Dakotas the maximum values are 17,500 feet. In other words, the satellite seems to be "looking" through the cirriform clouds (shown in fig. 18–3) to the tops of the altostratus. The cirrus and cirrostratus are apparently rather thin and are not absorbing and emitting much radiation in the window region.

Returning to the area of high clouds near the east coast, the height estimates from the satellite measurements are only about 22,000 to 28,000 feet, whereas heights of 30,000 to 33,000 feet were estimated from the pilot reports and other data. Since the cirrostratus clouds were rather thick, about 7,000 feet, the heights derived from the satellite temperature values correspond to the lower parts of the cirrostratus (or slightly below their bases). Thus, the cirrostratus clouds were only partially transparent to infrared radiation and were making a substantial contribution to the infrared radiation in the window region as measured by the satellite.

In summary, this case definitely illustrates that the radiation data in the water-vapor window can be very useful for approximate cloud-

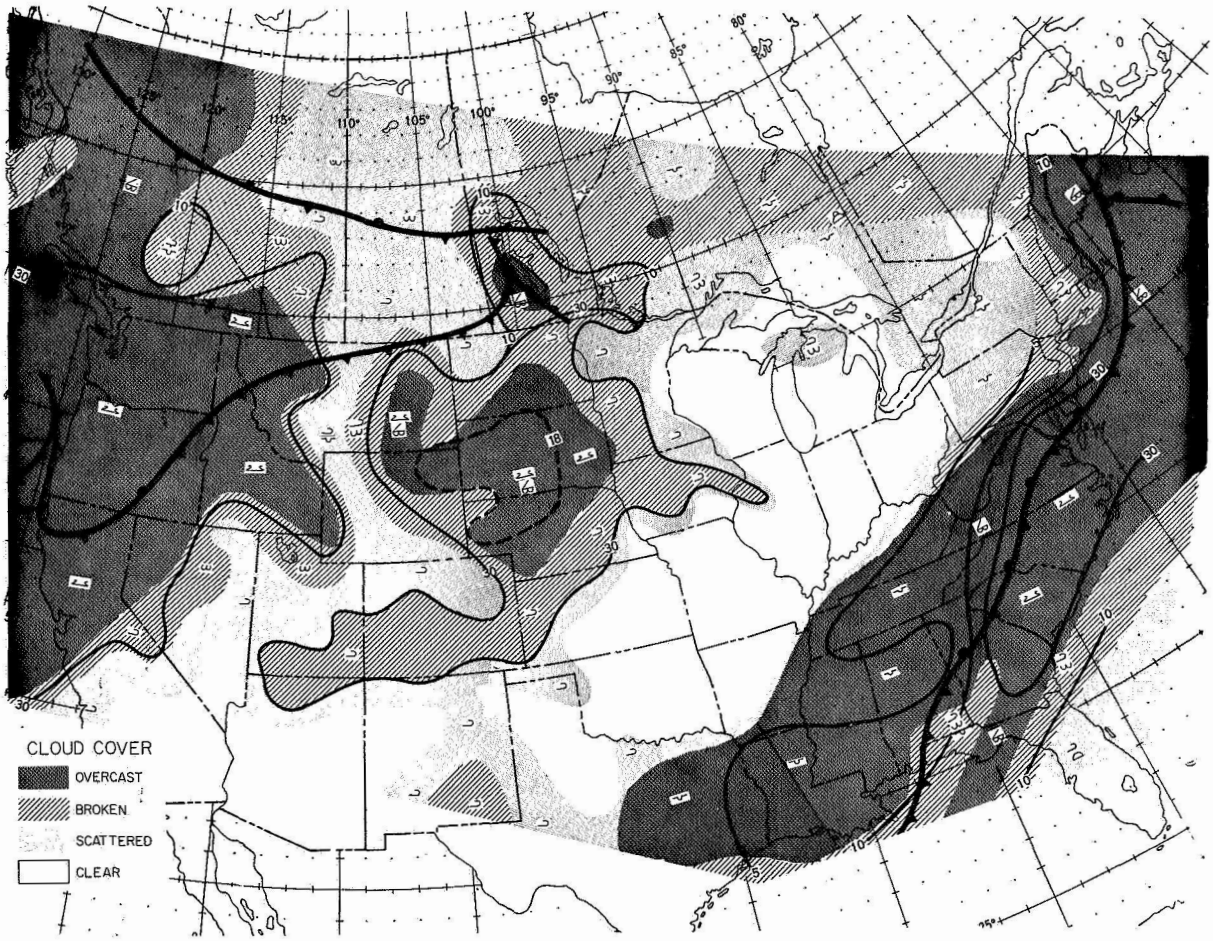

FIGURE 18–3. Cloud cover chart for 1800 GMT, November 23, 1960. Solid lines are contours of heights of cloud tops in thousands of feet.

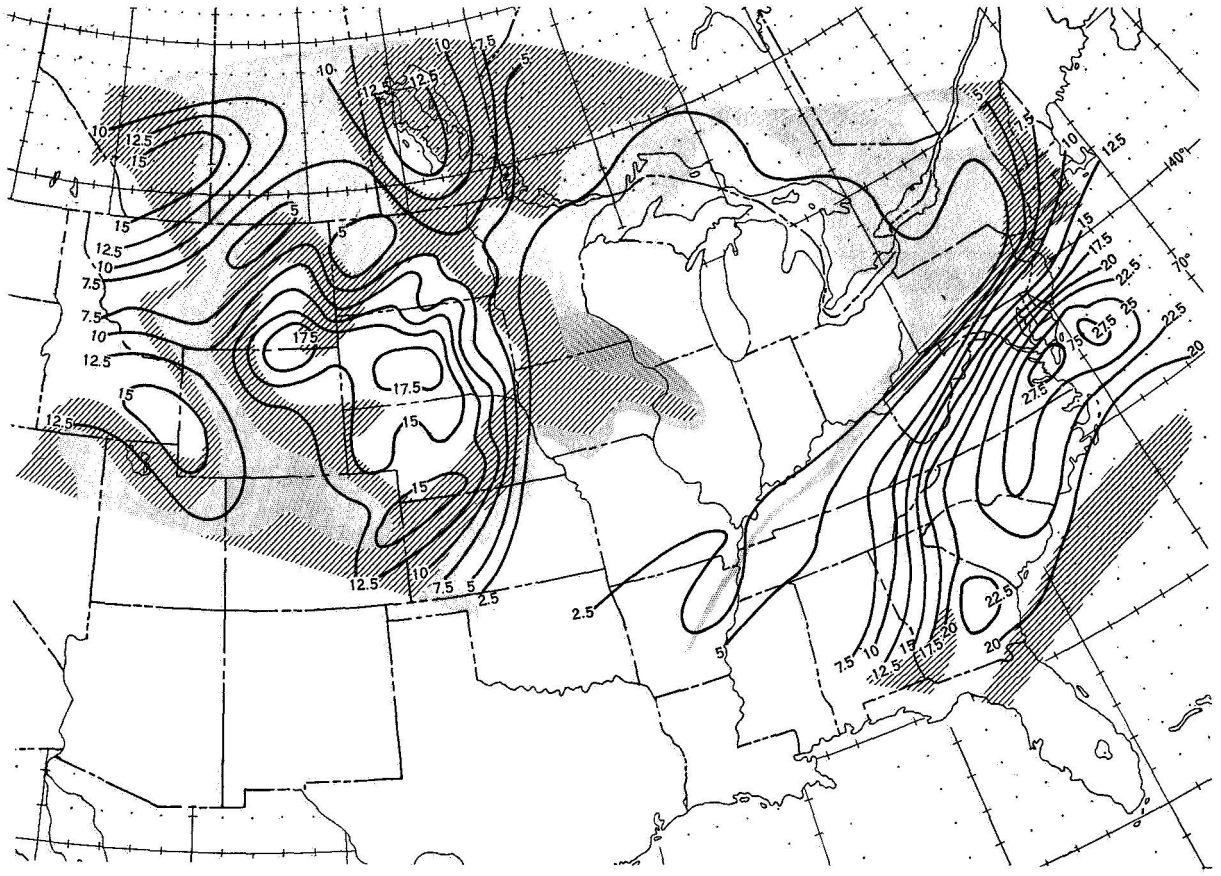

FIGURE 18–4. Heights of cloud tops (thousands of feet), 1800 GMT, November 23, 1960, as estimated from TIROS II radiation measurements. Hatched areas are the broken clouds of figure 18–3; dotted areas are the scattered clouds of figure 18–3.

top determination both night and day. In the daytime these data would be most useful in conjunction with satellite pictures. At night these data would be the only information on cloudiness available and would at least be useful for detecting extensive middle and high cloud systems.

The question of how these radiation data will be used as they are gathered over large areas of the earth and over longer time periods is the basic problem. It is expected that the capability for measuring the global heat budget in more detail will be increased. Then, a knowledge of the behavior of broad-scale heating and cooling will aid in determining how the atmosphere responds on a broad scale to this heating. Work thus far in this area has been to prepare for the time when these heat-budget measurements will be available. Investigations of some energy parameters in the atmosphere have been started. A brief discussion of this work follows.

Figure 18–5 shows a way of characterizing the energy cycle in the atmosphere. (See ref. 2.) This characterization, although applicable to the whole atmosphere in the strictest sense, must for practical purposes be treated as it applies to various portions of the atmosphere. Essentially there are only two basic forms of energy: kinetic energy and potential energy (the latter actually includes the internal energy when the entire atmosphere is considered). It is well known that the amount of potential energy is much larger than the kinetic energy and only very small changes in potential energy can produce all the changes that would ever occur in the kinetic energy. It is more convenient to deal only with that part of the potential energy which is available for conversion into kinetic energy, the available potential energy. Both the kinetic energy and available potential energy may be considered in terms of two components, zonal and eddy. Thus, there

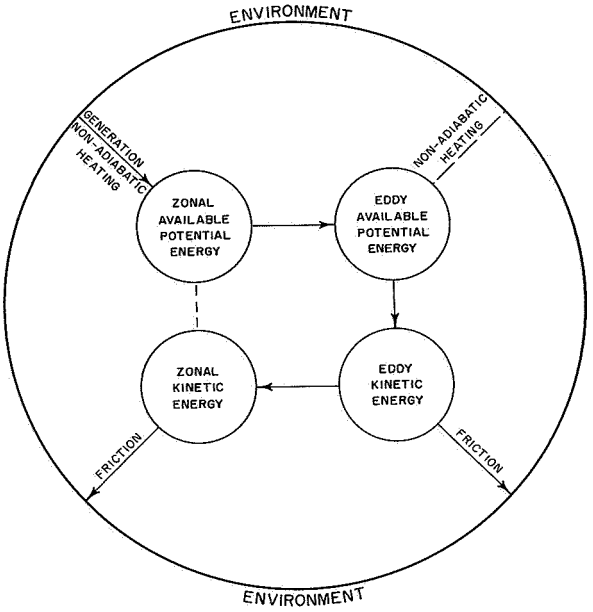

FIGURE 18–5. Proposed energy cycle for the atmosphere of the earth.

are zonal available potential energy, eddy available potential energy, zonal kinetic energy, and eddy kinetic energy. The kinetic energy is well known; it is a function of the square of the wind speed. The zonal component is essentially the kinetic energy of the mean zonal (west-east) flow. The eddy component is the energy of the deviations from mean zonal flow within latitude circles.

The available potential energy is mainly a function of the spatial variance of temperature on isobaric surfaces. The zonal component is a function of the variance of latitudinally averaged temperatures or, essentially, of the strength of the north-south thermal gradient. The eddy component is a function of the variance of temperature within latitude circles; it has a minimum value when the isotherms are parallel to the latitude circles and a maximum value when the isotherms display a wave pattern of large amplitude.

Consider the cycle illustrated in figure 18–5. Generally, if nonadiabatic (diabatic) heating occurs, zonal available potential energy or eddy available potential energy may be generated. Generation (positive generation) occurs when the heating and the temperature field are positively correlated; that is, when the warmer air is heated and the colder air is cooled. Of course, there would also be generation when there is cooling everywhere, as long as there is less cooling where the air is warm and more cooling where it is cold. If the heating is negatively correlated with temperature, that is, cooling of warm air and warming of cold air, then there would be dissipation (negative generation) of available potential energy. In general, at least in the colder season of the year, in the Northern or Southern Hemisphere, there is a tendency for generation of available potential energy.

The heat-budget data obtained from satellites will be of prime importance in determining this generation term. For the first time the net heating of the earth-atmosphere system will be measurable. Although the actual heating of the atmosphere itself must be known in order to determine the energy cycle, the earth-atmosphere heat budget might nonetheless give a gross measure of other heating processes as well as of radiation. In any event it is known that the net difference in radiation (in the winter season heating at low latitudes and cooling at high latitudes) generates zonal available potential energy.

The next stage in the energy cycle following generation of zonal available energy is conversion from zonal to eddy available energy. Essentially, this means that there is a buildup in the temperature gradients within latitude circles at the expenses of the zonal gradients. This is a familiar development in middle latitudes; in simplest terms it is related to the breakdown of a zonal type of flow with fast westerlies into a perturbed circulation of large-scale wave patterns where there are large exchanges of air between high and low latitudes. In fact, the key factor in the conversion from zonal to eddy available energy is the north-south heat transport; that is, the larger the values of heat transport are, the greater is the conversion to the eddy form of available potential energy.

Eddy available potential energy can also be generated by radiation differences within lati-

tude circles; for example, the differential heating between continents and oceans results in increased differences in temperature within the latitude circles. On the other hand, many times the heating is distributed so that there is a dissipation of eddy available energy by the heat sources, mainly in the case of the heating of air in exchange with the surface, for example, heating of cold air masses over warmer ocean currents in the winter.

Following the energy cycle through, once eddy available potential energy starts building, there is an almost simultaneous buildup in eddy kinetic energy. After this there may then be a conversion from eddy kinetic energy to zonal kinetic energy. Then, of course, both forms of kinetic energy are dissipated by friction.

Figure 18–6 shows samples of computations of energy parameters which are calculated from the analyses of Northern Hemisphere midtropospheric charts made at the National Meteorological Center. The parameters represent a substantial depth of the atmosphere over the entire Northern Hemisphere northward from 20° or 30° N. The case illustrated in figure 18–6 involves a very well marked cycle in zonal available potential energy. Note how this zonal available energy built up to a peak value on January 1 and then dropped rapidly in the first week of January. The drop in zonal energy was accompanied by a rise in the eddy available potential energy, which had a rather low value until just about the time the zonal available energy started falling. It appears that there was a conversion from zonal available to eddy available energy at this time.

The behavior of eddy kinetic energy during this cycle in available energy is also interesting. Eddy kinetic energy was relatively small

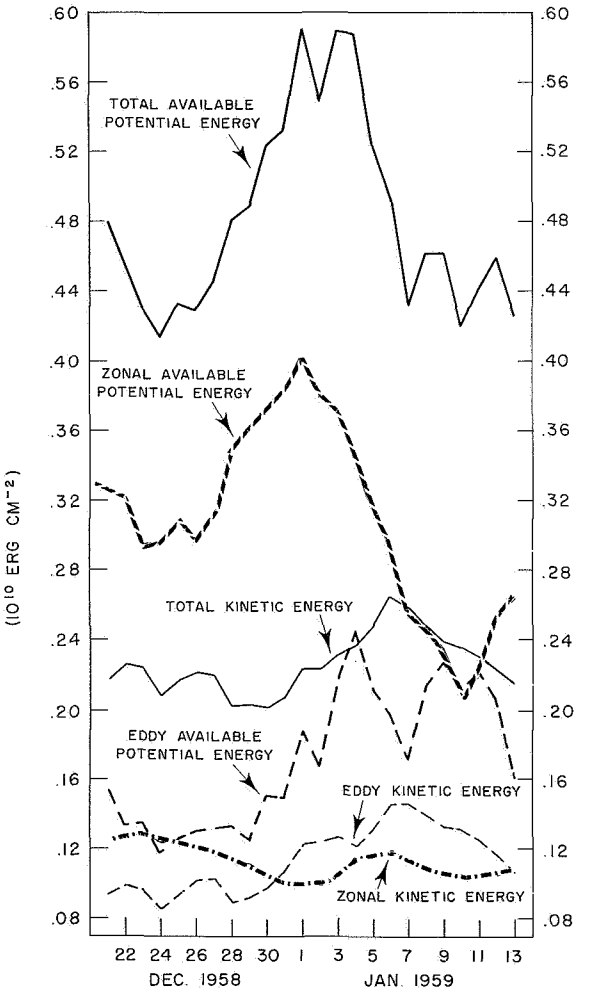

FIGURE 18–6. Time variation of available potential and kinetic energy and the zonal and eddy components of each. December 21, 1958, to January 13, 1959.

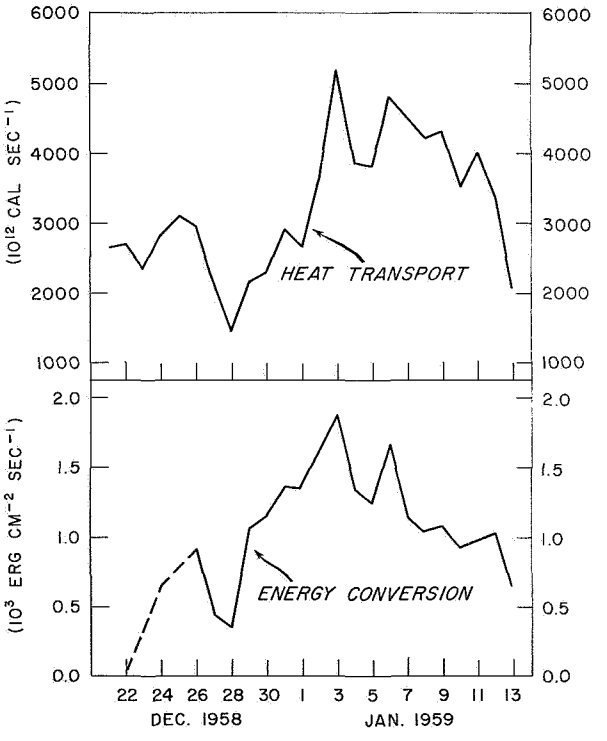

FIGURE 18–7. Total heat transport across all latitudes from 20° N northward and the conversion between available potential and kinetic energy. Same time period as in figure 18–6.

when zonal available energy was increasing, but it rose almost simultaneously with the eddy available energy. It actually reached a peak, however, a day or so beyond the peak in the eddy available potential energy. The zonal kinetic energy during this period showed some drop and then a slight rise, but basically it did not seem to take part to any extent in the general cycle found in the other forms of energy.

It is also of interest to examine briefly the heat transport for the same period (fig. 18–7). The expected relationship is shown: rather low values while the zonal available potential energy was building up, then a rapid rise indicating a large-scale north-south heat exchange which acts to convert zonal available to eddy available energy.

Figure 18–8 shows the available potential energy for the same case partitioned into energy in four specific regions rather than in the zonal and eddy forms. In this case these are wedge-shaped zones extending from about 30° north to the pole. Of most interest here is that the major variation, or cycle, in available potential energy showed up essentially only in zone 1 (over the North American area). Note that the energy values for the other areas did not change much. Thus, a large-scale cycle in available potential energy of the Northern Hemisphere as a whole was dominated by events in one region of the hemisphere—in this case the North American area. This shows the importance of paying close attention to geographical and synoptic-scale influences even in such large-scale studies as of the energetics of the atmosphere over much of the Northern Hemisphere.

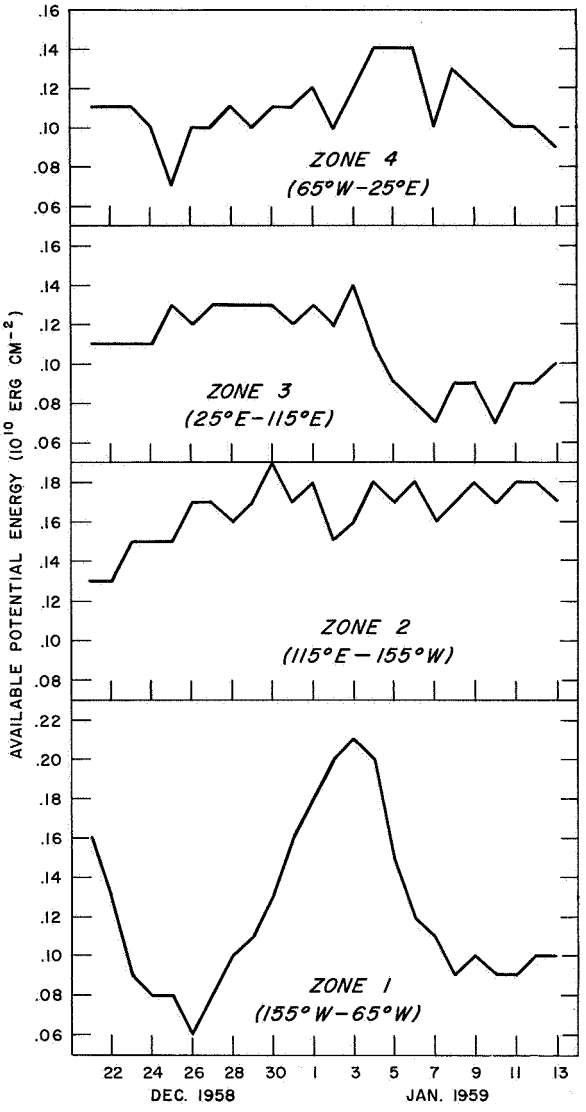

FIGURE 18–8. Time variations of available potential energy in four zones extending northward from 30° N. Same time period as in figure 18–6.

References

1. HANEL, R. A., and WARK, D. Q.: *TIROS II Radiation Experiment and Its Physical Significance.* Jour. Optical Soc. of America, vol. 51, no. 12, Dec. 1961, pp. 1394–1399.
2. WINSTON, JAY S., and KRUEGER, ARTHUR F.: *Some Aspects of a Cycle of Available Potential Energy.* Monthly Weather Rev., vol. 89, no. 9, Sept. 1961, pp. 307–318.

Question Period

SCHMIDT, Netherlands: I should like to ask whether any relationships have been found between latitudinal variations in radiation and intensity variations in the subtropical jetstream.

WINSTON: So far, no. There has been no study of this. This is all for the future.

PATRICK, Nigeria: In this paper, determining cloud heights from radiation data was mentioned. I was wondering whether a phenomenon like fog could actually be determined or whether the method used is not just giving the amount of liquid water content in clouds instead of providing information about the cloud heights.

I think some figures about the heat budget between 30° and the poles were shown. At that point, the conversion of kinetic energy to available potential energy was discussed. I was wondering what must have happened in the midlatitudes where there is indirect circulation. I feel that there kinetic energy is being converted into

available potential energy. Are certain of the conclusions made justified? I feel that the heat budget in the equatorial belt, which is the driving force in winter for the whole general circulation, was neglected.

WINSTON: With regard to the last point, the arrows in the depiction of the energy cycle were for the prevailing direction of conversion as determined from empirical studies at MIT, UCLA, and other places. Where there are no arrows, no prevailing direction is indicated. However, at certain times there can certainly be a flow of energy which is opposite to the prevailing directions. With regard to the indirect meridional cell, I believe the evidence is that this cell does not play an important role in the total conversion between potential and kinetic energy in middle latitudes.

In regard to the tropical and equatorial regions, your comments are quite right. So far our studies have been confined to midlatitudes, from about 20° to 30° northward. We are not doing any measuring of the contributions of the Hadley cell; this is part of the problem which needs more attention.

The other question about fog, I am not sure I know how to answer. Essentially, if fog is present and that is the only cloud, the values should be rather high. If there is fairly moist air, you will not be able to distinguish the surface from the cloud. But if you also have pictures taken at the same time (or measurements from the visual portion of the spectrum), you will be able to tell whether there is or is not a cloud deck. If you are going to make an estimate of height from an effective radiating temperature, the height value will be low. We do not claim that such estimates are going to be accurate to any closer than a few thousand feet. With window measurements alone you could not be sure whether the satellite is viewing the surface of the earth or a cloud top within a few thousand feet of the surface.